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Swelling Bentonite Clay

.....a new forest fire retardant

BY C.B.PHILLIPS
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PACIFIC SOUTHWEST FOREST & RANGE EXPERIMENT STATION
KEITH ARNOLD, DIRECTOR . . . . . BERKELEY CALIFORNIA

SWELLING BENTONITE CLAY--

A NEW FOREST FIRE RETARDANT

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U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
PACIFIC SOUTHWEST FOREST AND RANGE EXPERIMENT STATION

FOREWORD

Laboratory and field tests show that swelling type bentonite clay is a good forest fire retardant. Its effectiveness lies in its ability to absorb and retain a large amount of water for 2 to 3 hours under summer drying conditions. Its advantages compared to sodium calcium borate include: relatively low cost; non-abrasiveness in transfer pumps; non-toxic and non-corrosive qualities; and relatively low weight per gallon of slurry resulting in a greater safety margin for air tankers. Its disadvantages include: effective as a retardant for a shorter time; must be colored by an additive; and has certain mixing, storing, and transferring characteristics which should be understood before it is used. Information on mixing, storing, and transferring bentonite can be obtained by writing to the Director, Pacific Southwest Forest and Range Experiment Station, Berkeley 1, California.

ACKNOWLEDGMENTS

Thanks are due for technical help and information for this study and the present report from the following sources: Walter F. Rogers, Gulf Oil Corporation, Houston, Texas; American Colloid Company, Chicago, Illinois; Brown Mud Company, Torrance, California; George Gates, U. S. Bureau of Mines, San Francisco, California; Frederick R. Kelley, California Division of Mines, San Francisco, California; Orien Van Dyke, Magnet Cover Barium Corporation, Houston, Texas; and R. W. Wilson, Baroid Division, National Lead Company, Houston, Texas.

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SWELLING BENTONITE CLAY--A NEW FOREST FIRE RETARDANT

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and
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Laboratory and field tests a few years ago (Firestop, 1955; Miller, 1956; Miller and Wilson, 1957) established sodium calcium borate as the most effective fire retardant available for forest fire suppression. Since 1956 forest fire fighters have used this material with increasing success (Anonymous, 1956; Miller and Reinecker, 1958). Further screening tests of several materials indicated that swelling type bentonite clay might be superior in some respects to sodium calcium borate (Miller and Phillips, 1958) and led to a comparative study of the two materials.

This study, made in 1958[2/], showed that swelling type bentonite clay, commonly used in oil-well drilling mud, is a good forest fire retardant. Mixed with water, it sets up into a stable gel and retains water tenaciously for periods up to 2 or 3 hours under summer drying conditions. In 26 trial air-tanker drops on 12 wildfires in California in 1958, bentonite appeared to be at least as effective as sodium calcium borate. This relative effectiveness was also shown in a series of laboratory tests with bentonite-coated wooden dowels and in field trials on grass and piled brush. All these tests showed that bentonite was effective as a retardant only for the 2 to 3 hour period that it was able to hold water. Beyond that time it could not be depended upon as a retardant.

Considering the cost of the material and its mixing ratio with water, bentonite is one-twelfth as expensive as borate in California. Its cost advantage increases closer to the sources of bentonite and farther from the one commercial source of borate. Because the slurry of bentonite requires only three-fourths of a pound of bentonite to a gallon of water (about one-fifth the rate of borate), transportation and handling costs are relatively low.

1/ On assignment to the Pacific Southwest Forest and Range Experiment Station for 1958 and 1959.

2/ Tests were conducted in California by the Pacific Southwest Forest and Range Experiment Station, Division of Forest Fire Research. Cooperators in the field tests included Region 5, U. S. Forest Service; Arcadia Equipment Development Center, U. S. Forest Service; California Division of Forestry; and Los Angeles County Fire Department.

Bentonite clay is relatively non-abrasive when used in pumps. It is non-toxic to animals and plants, does not compact under prolonged storage, is non-corrosive to metals, and mixes easily into a stable gel which becomes fluid upon agitation or which can be kept fluid by the addition of certain inexpensive chemicals.

When dropped from an air tanker, bentonite provides much the same drop pattern as borate, penetrates the vegetative canopy in a similar way, and coats different fuel types in much the same manner (fig. 1). The natural bentonite slurry was not easily visible from the air when dropped from an air tanker. So that air tanker pilots could readily tell where previous drops had been made and deposit a continuous line of retardant, the bentonite had to be colored. A pink aniline dye, which mixed easily with the slurry and added less than a cent per gallon to the cost of the slurry, was found to be the best material and the best over-all color.

Figure 1.--The slurry of swelling bentonite clay readily coats various surfaces and holds a large amount of water in place for periods of 2 to 3 hours.

LABORATORY AND FIELD TESTS

The evaluation of bentonite as a forest fire retardant is based on laboratory tests of ignition and radiant heat energy output on grass plot tests, on brush pile tests, and on observations of air tanker drops made on wildfires. These tests generally gave the same results: bentonite was at least as effective a retardant as borate for 2 to 3 hours under severe drying conditions. After that time, it was less effective than borate. Under less severe drying conditions that those in the experimental trials, bentonite might be effective for a longer period, as was suggested by one air tanker drop on a fire in Lake County: the drop was made at 5:30 P.M. one evening and at 10:30 A.M. the next morning the bentonite slurry was still thoroughly wet, drying out gradually as the morning sun warmed the area.3/

LABORATORY TESTS

A mixture of .94 pounds of bentonite per gallon of water was used for all laboratory tests. These tests were made before field trials showed that a thinner mix was desirable for ease in pumping the slurry.

One series of tests compared the time required to ignite retardant-treated and water-treated wooden dowels. Briefly the procedure was as follows (for details, see appendix and Fons, 1950):

1. Wooden dowels were dried for 24 hours in an oven at 120° F. (fig. 2).
2. The dowels were treated with retardant or water.
3. After additional drying at 120° F., the dowels were placed one at a time in a muffle furnace and left until they ignited (fig. 3), and the time required for ignition was recorded. Separate tests were made with dowels dried 1, 2, 3, 4, and 5 hours.
4. The above procedure was followed for muffle furnace temperatures of 1,000° F., 1,200° F., 1,500° F., and 1,700° F.

The results can be summarized as follows (detailed results are in the appendix):

1. Bentonite and borate were both more effective than plain water in retarding ignition at all oven temperatures and for all drying periods.
2. Bentonite was more effective than borate in retarding ignition at temperatures of 1,000° F. and 1,200° F. for all drying periods.
3. Bentonite was more effective than borate in retarding ignition at 1,500° F. and 1,700° F. for 1 and 2 hours of drying. After 2 hours borate was more effective.

3/ Roadside #18 Fire. See Table 4, Appendix.

Figure 2.--Dowels used in the laboratory ignition and radiation tests were dried in a forced convection drying oven.

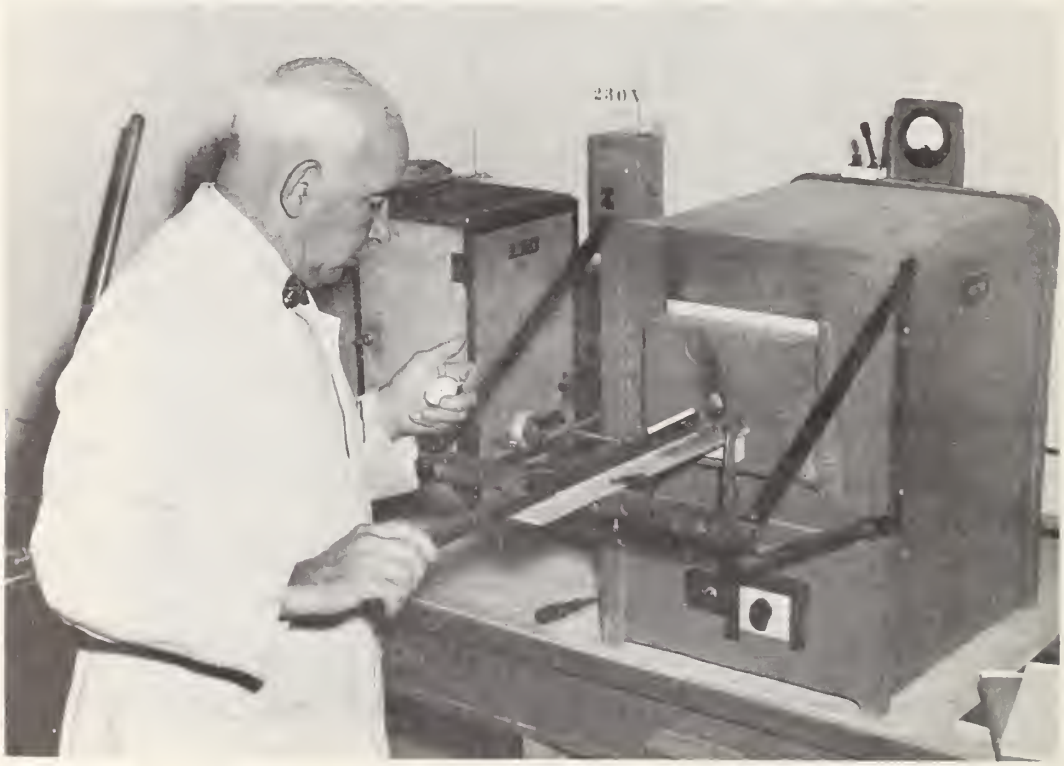

Figure 3.--In the ignition tests, the dowels were inserted into a muffle furnace, and the time for ignition to take place was recorded.

Another series of tests compared the ability of the chemical retardants and water to decrease radiant heat energy output from burning dowels. Briefly the procedure was as follows (for details, see appendix):

1. Wooden dowels were dried 24 hours in an oven at 120° F.
2. Half the dowels were treated with retardant or water.
3. After additional drying, treated dowels were placed on a fire wheel, alternately with untreated dowels, the dowels were ignited, the wheel whirled, and the radiation level measured by a radiometer and recorded continuously on a potentiometer. The same procedure was followed after 1, 2, 3, 4, and 5 hours of drying.

In summary the tests showed (detailed results are in the appendix):

1. Bentonite was more effective than borate or water in reducing both total radiation and peak radiation for all drying periods.
2. Borate was more effective than water in reducing both total radiation and peak radiation for all drying periods.

GRASS PLOT TESTS

Bentonite was compared with borate on 8 treated grass plots, each about 30 feet wide and 20 feet long. A 3-foot strip was treated with bentonite at one end of four of the plots, and with borate on the other four plots. The same number of gallons of bentonite and borate slurry was applied uniformly on each plot. The heavy grass and other annuals averaged 4 feet high and were extremely dry. The tests were conducted at Parks Air Force Base, Alameda County, on September 18, 1958. Air temperature varied from 83° F. to 95° F.; relative humidity from 37 percent to 18 percent. There was little or no wind during the tests.

Plots treated with each type of retardant were burned after 1, 2, 3, and 4 hours of drying. The dry heavy fuels produced hot fires on all plots (fig. 4).

Bentonite strips that had dried 1 and 2 hours stopped the fire abruptly (fig. 5). Where bentonite had dried 3 hours, the fire burned slowly through the tops of the fuel in the treated strip but did not penetrate the matted lower layers which were still wet. Borate stopped the fires on plots dried up to 3 hours. On plots dried 4 hours, the fire burned readily through the fuel treated with bentonite and burned slowly through the fuel treated with borate. In summary, the retarding effect of bentonite and borate on these tests fires was as follows:

Drying time, hours:	Bentonite	Borate
1	Complete stop	Complete stop
2	Complete stop	Complete stop
3	Retarded	Complete stop
4	Burned through	Retarded

Figure 4.--Flames averaged 10-15 feet in height in grass plots on which bentonite and borate were compared.

Figure 5.--This strip of grass, sprayed with bentonite slurry, stopped the test fire abruptly after the slurry had dried for 2 hours.

Figure 6.--Dry, flashy chamise fuel produced flames averaging 15-20 feet in height on all brush piles.

Figure 7.--Flame height was lower (and forward spread slowed) in brush treated with either bentonite or borate than in untreated brush.

BRUSH PILE TESTS

Bentonite was compared with borate on 8 treated brush piles, each about 2 feet high, 10 feet wide, and 15 feet long. About 5 feet of the length was treated with bentonite at one end of four of the piles, and with borate on the other four piles. Again, the same number of gallons of bentonite and borate slurry was applied uniformly on each pile. The piles were composed of chamise stems that had been cut from a firebreak and dried for nearly 3 years. The largest stem was about 1 inch in diameter. The tests were conducted near Callandra Lookout, Monterey County, on September 19, 1958. Air temperature varied from 85° F. to 89° F. during the burning tests; relative humidity from 18 percent to 14 percent. Winds were gusty and variable but averaged about 6-8 miles per hour from the north over the open ridge where the burns were held.

Again the retardant dried 1, 2, 3, and 4 hours before burning the piles. The dry, flashy fuels produced hot fires in all piles (fig. 6). Heat energy was measured by a radiometer. These measurements, however, were influenced to an unknown degree by the wind and therefore may not reflect the heat output accurately. Furthermore, the gusty, variable wind made burning conditions unlike in some of the tests: the wind drove the flames directly into the treated part of the brush piles treated with bentonite 1 and 3 hours earlier. In all other piles the flames backed against the wind into the treated area. Radiometer measurements indicated that the pile treated with bentonite and dried 3 hours produced by far the hottest fire (table 1).

No fires were completely stopped as in the grass plot tests, but all were retarded to some degree. Judging from the observed reduction in flame height and spread (fig. 7) and from study of the radiometer measurements, the retarding effect was rated as follows:

Drying time, hours:	Bentonite	Borate
1	Fair	Very good
2	Good	Very good
3	Fair	Good
4	Good	Good

TESTS ON WILDFIRES

The final step in the testing procedure was to compare bentonite and borate on wildfires. It was decided to make the tests from airports where air tankers could drop both bentonite and borate on the same fire under similar burning conditions. Two initial attack organizations were selected to make the drops: the California Division of Forestry operation at Hobergs Airport in Lake County, for northern California fires in grass, brush, and timber; and the U. S. Forest Service, Region 5, operation at Ontario Airport in San Bernardino County, for southern California fires in dense brush fields. Because of the limited mixing and

storing facilities of the bentonite testing operation at each location, more drops of borate than bentonite were made on most fires.

One 120-gallon Stearman air tanker and one 180-gallon N3N air tanker operated out of the Hobergs Airport. On each initial attack bentonite was dropped by one air tanker, borate by the other. The tanker carrying bentonite was alternated on each successive fire. Twelve loads of bentonite were compared with borate on 8 fires from August 31 to September 4, 1958. These fires included 4 in brush, 3 in grass, and 1 in light slash of redwood and Douglas-fir.

Table 1.--Potentiometer readings from radiometer measuring radiant energy produced by brush pile fires[1/]

Time after ignition, minutes	Bentonite, dried--				Borate, dried--			
	1 hr	2 hrs	3 hrs	4 hrs	1 hr	2 hrs	3 hrs	4 hrs
	Millivolts							
1	3.25	2.00	2.25	1.00	2.00	8.00	1.75	
2	8.00	9.50	12.50	10.50	7.50	15.25	9.50	
3	6.25	13.00	18.50	12.00	11.50	14.75	8.00	
4	2.75	7.75	10.25	7.25	8.50	8.25	3.00	
5	1.75	4.75	6.00	3.25	6.25	4.50	1.00	
6	1.50	1.50	5.00	1.75	3.50	2.25	-	
7	1.00	.75	3.50	-	2.00	1.50	-	
8	1.25	.50	3.00	-	.75	1.25	-	
9	1.25	1.00	-	-	.50	.75	-	
10	1.50	.75	-	-	.25	.75	-	

1/ Line across data columns at 3 to 5 minutes burning time indicates sharp decline in heat output when flames reached treated part of brush piles.

Figure 8.--Results of air tanker drop of bentonite in light slash and grass fuel. Fire outflanked drop but did not burn through.

The effectiveness of the drops, all of which were made immediately ahead of the fire line, was closely observed and photographed from the air. Four of the drops were later observed and photographed on the ground. Eleven of the drops of bentonite were made on wildfires, and all stopped the spread of the fires. The twelfth was made on a quarter-acre grass fire already controlled by ground crews. The fires sometimes flanked a drop of bentonite, but did not burn through (fig. 8). On these same fires most of the borate drops were effective in stopping or retarding the fire although a few drops were noted to be ineffective on the M. Barney Fire in Lake County on September 1.

At the Ontario Airport, 14 drops of bentonite were made on 4 fires by 4 different TBM air tankers between the dates of September 25 and October 4, 1958. Borate was dropped on the same fires by other air tankers. Again the effectiveness of all bentonite drops was observed and photographed from the air. One drop was later observed and photographed on the ground.

Again, all observed drops showed bentonite was an effective fire retardant. A few of the drops on the Monrovia Fire were flanked by the fire, but in no observed case did the fire burn through the bentonite soon after it had been dropped. Borate was also effective in most cases although hot rolling flames on portions of the highly intensive Monrovia Fire burned through some drops and flanked others.

Results of the tests of bentonite made on wildfires are summarized in Table 4 in the Appendix. Comparable tests of borate have been made in past experiments and the results published (Miller and Wilson, 1957).

DROP PATTERNS

To compare the drop patterns of bentonite and borate, the slurries were dropped into a stand of mixed brush and pine saplings with a crown canopy density of 70 percent and an average height of 5 feet. The average air temperature was 74° F., relative humidity 20 percent, and winds 3 miles per hour from the northwest. Conditions varied only slightly during the morning test period. Both the Stearman and the N3N planes at Hobergs Airport made one drop each of bentonite and borate, the four drops being approximately parallel to each other and all confined within a 2-acre area.

Observations and photographs showed no apparent difference between bentonite and borate in the following characteristics:

1. Dispersion in the air as the slurries left the air tankers.
2. Drop patterns on the ground.
3. Ability to penetrate the vegetative canopy--both retardants coated the ground litter immediately around the base of the stems of manzanita and scrub oak.
4. Manner of coating the vegetation--both retardants set up in globules on the needles of pine trees and on the new, waxy leaves of manzanita; both made continuous coats on the older leaves of manzanita and all leaves of scrub oak, coating both sides of some leaves.

Drying characteristics of the two retardants were also observed. After 30 minutes all but a few heavy concentrations of the borate located in deep shade had dried. This same condition was reached by the bentonite after 90 minutes. The dried borate left a relatively thick coating on the vegetation; the dried bentonite made a relatively thin coating owing to the smaller amount of dry material in the slurry.

NEED FOR COLORING

Pilots at Hobergs Airport who first made drops of bentonite from air tankers discovered in looking back that they could not see where their drops had been made. In tests of materials to make bentonite slurry more visible from the air, pink aniline dye was found to be the best general purpose coloring. Yellow dye was best for green vegetation but did not show well on dry grass. Deep shades of red were good on dry grass but did not show well on dark green vegetation. White pigments, such as titanium dioxide and calcite, did not mix well with the bentonite slurry, and the addition of large amounts (up to 25 percent by weight) did not effectively change the color of the slurry. Rhodamine B 500 percent concentrate, pink aniline dye, was found to be good on all vegetative types and is recommended as the best color compromise.

DISCUSSION

Fire retardants have now been used successfully in air tankers for 3 years. The 1958 tests of swelling bentonite clay showed that it is a good forest fire retardant for 2 to 3 hours under summer drying conditions. Bentonite, as compared with sodium calcium borate, demonstrated several desirable characteristics:

1. Sets up into a stable, viscous gel, becoming fluid upon agitation.
2. Is relatively cheap, being one-twelfth the cost of borate in California and giving an even better cost advantage in other areas.
3. Is readily available in many locations.
4. Is relatively non-abrasive in pumps.
5. Is non-toxic to plants and animals.
6. Does not compact under prolonged storage.
7. Is non-corrosive to metals used in mixing, storing, and pumping equipment.
8. Requires considerably less warehousing and handling because its mixing ration with water is one-fifth that of borate.

Bentonite also showed some disadvantages when compared with borate:

1. Is effective as a retardant for only 2 to 3 hours, depending on the fuel, volume of the drop, and drying conditions. Therefore bentonite cannot be relied upon for pretreatment for longer periods.
2. Should have color added, especially on large fires where many drops are required.
3. Viscosity must be controlled by agitation, addition of water or dry bentonite, or by use of dispersants.
4. Transfer lines must be flushed occasionally.
5. Hard water will tend to reduce the water-holding capacity of bentonite. It must be controlled by use of water-softening agents.

The tests with bentonite suggested several possibilities for further studies of the material as a fire retardant. Because of the many diversified uses of bentonite, there are several grades and forms of the material. Some of these may be found to be more desirable than oil-well grade for specific equipment used in fighting forest fires. The water held by the bentonite clay particles perhaps can be made more effective in retarding fire by such additives as evaporation inhibitors, flame inhibitors, foaming agents, or viscosity agents. One source of swelling bentonite in southern California is reported to contain a small percentage of fluorine, which is known to have certain flame inhibiting qualities. Exploration of such possibilities may help develop a better fire retardant.

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APPENDIX

LABORATORY TESTS

Radiation Tests

The effect of fire retardants on radiant heat energy produced by test fires was determined by comparing fires of fuels treated with retardants with control fires burning fuels treated with water.

Two hundred and thirty ponderosa pine (sapwood) dowels, one-half inch in diameter by 9 inches long, were used for a single test of each retardant: 5 holders with 22 dowels each for a total of 110 dowels to be treated with retardant and used in 5 different hourly tests; 1 holder with 6 dowels to be treated with retardant and used as a control to measure changes in weight during the hourly tests; 4 dowels to be used to measure the moisture content of the fuel; and 110 dowels to be used as controls.

Following is the procedure used:

1. 120 dowels were oven-dried at 120° F. for 24 hours.
2. 116 of the 120 dowels were then put in holders--5 holders with 22 dowels each (110) and 1 holder with 6 dowels (6).
3. The remaining 4 dowels of the 120 were cut into 1-inch lengths and their moisture content determined by xylene distillation.
4. The holder containing 6 dowels was weighed and the net weight recorded.
5. After cooling at room temperature for 10 minutes, the dowels in all six holders were dipped quickly in and out of the fire retardant being tested. The 5 holders with 22 dowels each were immediately put in the drying oven at 120° F. The holder containing 6 treated dowels was weighed again and put in the oven.
6. After 1 hour in the oven, one holder with 22 dowels and the holder with 6 dowels was removed from the oven. The holder containing 6 dowels was weighed and replaced in the oven.
7. The 22 dowels were then removed from their holder and placed in 2 circular rows on the firewheel, alternated with 22 untreated dowels.[4/]
8. The dowels were ignited with 2 gas rings, one inside the double row and one outside. The firewheel turned at 22 rpm driven by a constant speed motor.
9. Radiant heat was measured by a Gier and Dunkle directional radiometer and continuously recorded with the G. E. recording potentiometer (fig. 9).

4/ These untreated dowels, 110 in all for the 5 hourly tests, were oven-dried at 120° F. for 24 hours prior to the test in which they were used and were taken from the oven as needed.

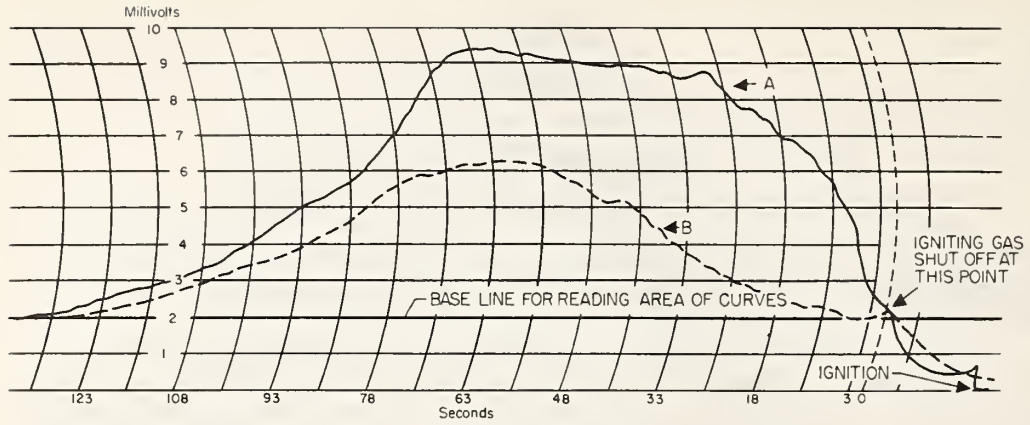

Figure 9.--Radiometer trace for control fire (A) and test fire (B).

10. When the potentiometer reached a reading of "2" on the recording scale, the gas was shut off.
11. The fire was allowed to burn until the potentiometer dropped back down to "2" on the recording scale.

At 1-hour intervals steps 6 to 11 were repeated to test retardants dried 2, 3, 4, and 5 hours. After the radiation tests were completed, the 6-dowel group was dried for 24 hours and then weighed. Each test was done three times and the results averaged.

Water-treated fuels for control fires were tested with the same procedure outlined above.

The total radiant energy output of each fire was determined by measuring the area under the radiometer trace (fig. 9). A "radiation ratio" was then computed by expressing the trace area for the test fire as a percent of the trace area for the control fire. A ratio for the peak radiation of the test fire to that of the control fire was similarly computed.

In the results of these tests (table 2), the lower the ratio, the more effective was the retardant in reducing radiant heat output. The "0" radiation ratio for bentonite after 1 hour of drying resulted from the fire dropping below the "2" point on the recording scale immediately after it had reached this point through forced ignition. This test fire never did rise to the "2" point again. The total radiant heat output from bentonite-treated fuels reached a maximum of 9.9 percent of that for the control fire for fuels dried 4 hours. Results of these tests are also shown graphically in Figures 10 and 11.

Fire Ignition Tests

The effect of fire retardants on ignition time was determined by comparing the time required for the ignition of fuels treated with retardant with time required for the ignition of fuels treated with water. The dowels were ignited by insertion in a muffle furnace. Birch dowels, one-quarter inch in diameter by

Table 2.--Effect of bentonite and borate on radiant heat energy output 1/

Hours after treatment	Total radiation		Peak radiation ratio	
	Bentonite	Borate	Bentonite	Borate
	Percent of control			
1	0	48.2	16.8	69.6
2	.24	66.1	20.7	85.9
3	7.8	67.9	37.8	79.0
4	9.9	75.1	38.2	81.1
5	6.7	79.7	38.2	81.6

1/ Average of 3 tests per treatment.

5 inches long, were used for the ignition test. The tests included 4 oven temperatures with retardant-treated fuels dried 1, 2, 3, 4, and 5 hours. For each 20 tests, 64 dowels were used: 50 dowels were treated with retardant and used in 5 different hourly tests; 6 dowels were treated with retardant and used as a control to measure the changes in weight during the tests; and 8 dowels were used to measure the moisture content of the fuel.

Following is the procedure used for the ignition tests:

1. Sixty-four dowels were oven dried at 120° F. for 24 hours.
2. The dowels were removed and all but 8 put into 10 holders of 5 dowels each and 1 holder of 6 dowels.
3. The remaining 3 dowels were cut into 1-inch lengths and their moisture content determined by xylene distillation.
4. The holder containing 6 dowels was weighed and the net weight recorded.
5. After cooling at room temperature for 10 minutes, the dowels in all 11 holders were dipped quickly in and out of the fire retardant being tested. The 10 holders having 5 dowels each were put in the drying oven, at 120° F. The holder with 6 treated dowels was weighed again and then put in the oven.
6. After 1 hour in the oven, the holder with 6 dowels and 2 holders with 5 dowels were removed from the oven.
7. The holder containing 6 dowels was weighed and replaced in the oven.

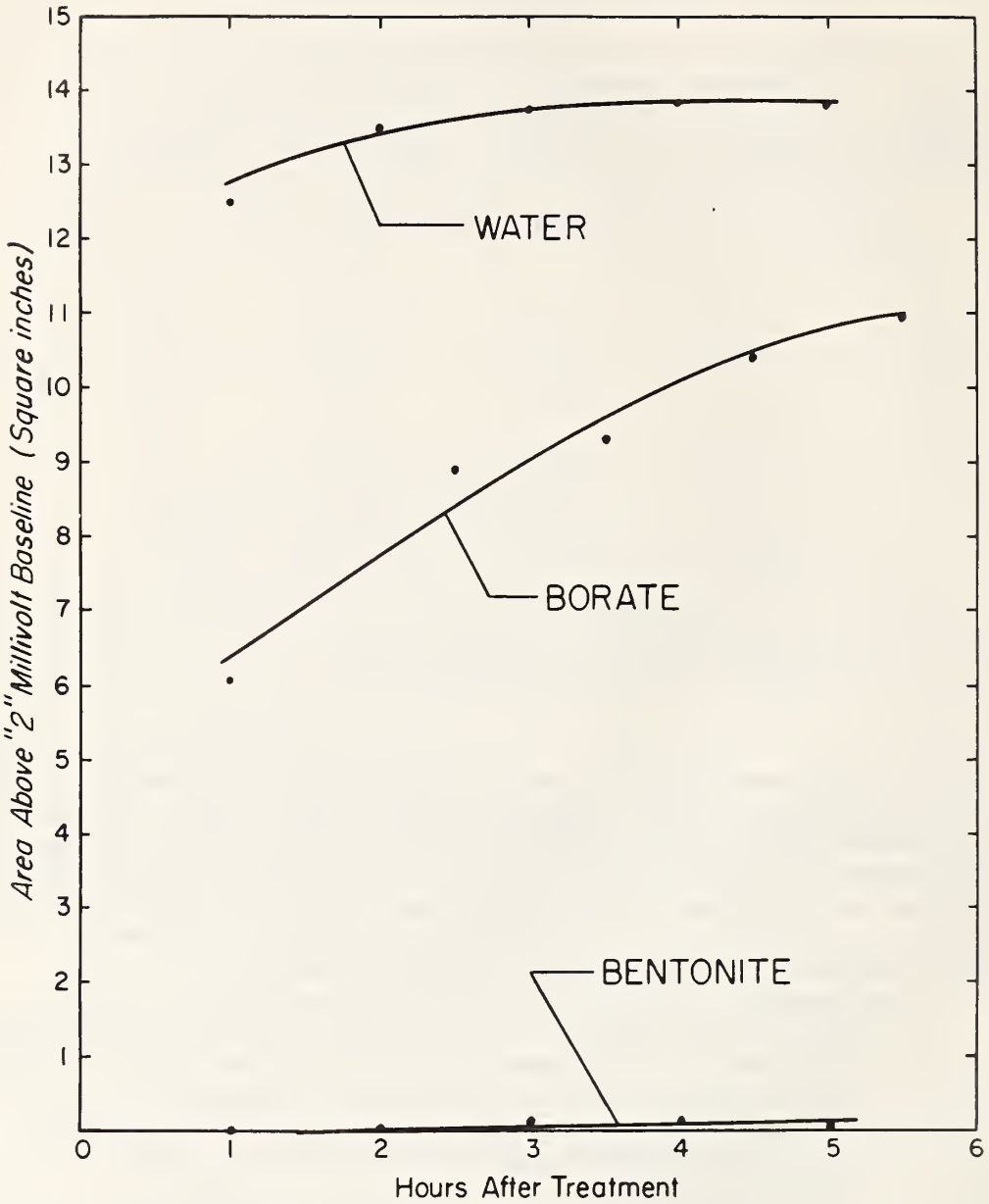

Figure 10.--Radiation tests, total heat energy output, (based on area measured in square inches above "2" mv. baseline).

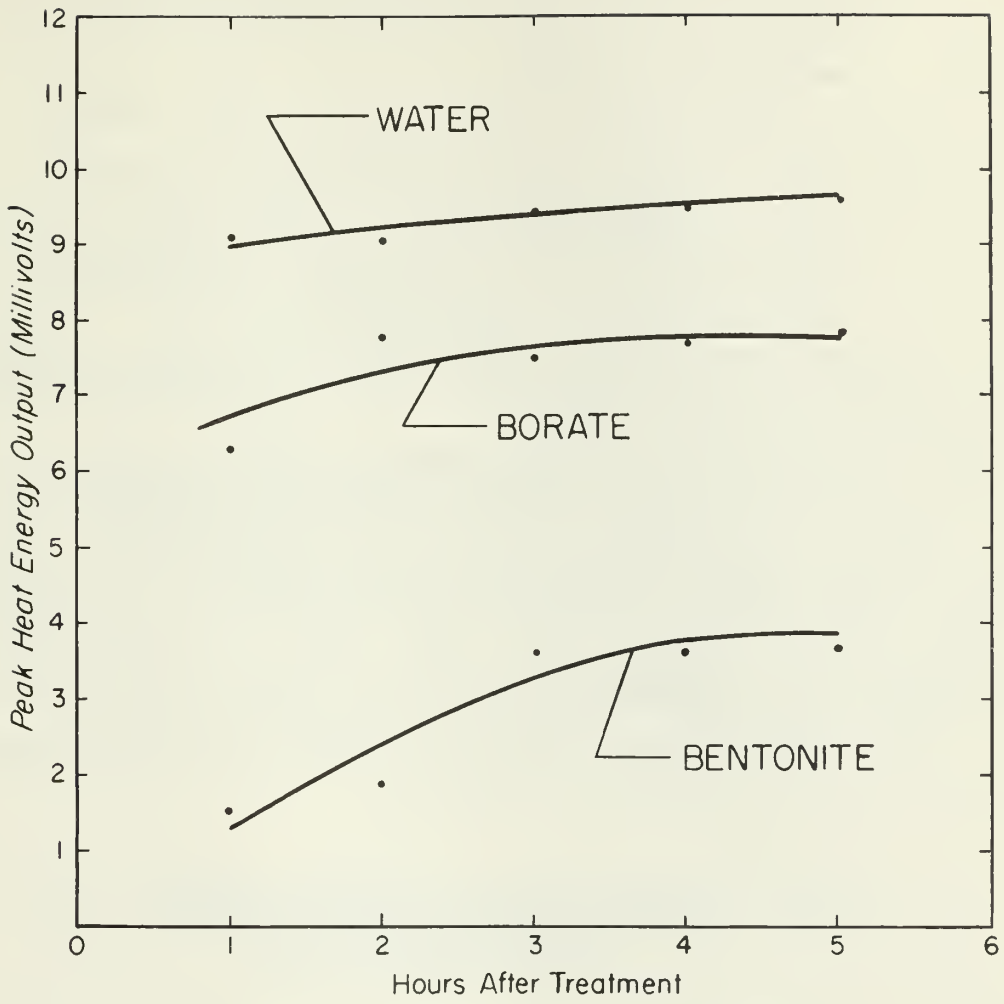

Figure 11.--Radiation tests, peak heat energy output.

8. The 10 remaining dowels were inserted one at a time into the muffle furnace at a temperature of 1,000° F. The time for ignition (the time from insertion until the dowel burst into flame) was measured and recorded for each of the 10 dowels.
9. At 1 hour intervals steps 6 through 8 were repeated for a total of 5 tests.
10. After the ignition test was complete, the 6-dowel group was dried for 24 hours and then weighed.
11. Steps 1 through 10 were then repeated for each retardant with the muffle furnace temperatures being changed to 1,200° F., 1,500° F., and 1,700° F. in step 8, for a total of 20 tests for each retardant.

Water-treated fuels for control fires were tested using the same procedure in steps 1 through 11. Each test was repeated three times and the results averaged.

An ignition ratio was then computed by expressing the results of the tests with retardant-treated dowels as a percent of the results of the control tests with water-treated dowels.

Borate and bentonite were both very effective in increasing ignition time (table 3). Bentonite was more effective than borate for all drying periods at 1,000° F. and 1,200° F. and for 1 and 2 hours drying at 1,500° F. and 1,700° F. After 3 or more hours of drying, borate-treated fuels required a longer time for ignition at 1,500° F. and 1,700° F. than did bentonite-treated fuels.

The ignition times of bentonite-, borate-, and water-treated fuels are shown in figures 12 through 20.

Table 3.--Ignition time of retardant-treated fuels as percent of ignition time of water-treated fuels

Hours after treatment	1,000° F.		1,200° F.		1,500° F.		1,700° F.	
	Bentonite	Borate	Bentonite	Borate	Bentonite	Borate	Bentonite	Borate
1	239.6	148.3	280.8	145.2	248.6	193.5	298.3	241.0
2	172.7	124.1	190.2	129.2	187.1	185.6	244.7	238.8
3	162.3	123.0	155.9	131.6	161.5	117.0	198.8	231.4
4	149.5	119.6	142.9	130.0	155.5	182.9	190.0	221.8
5	146.8	122.0	132.5	123.5	150.9	184.0	182.9	210.0

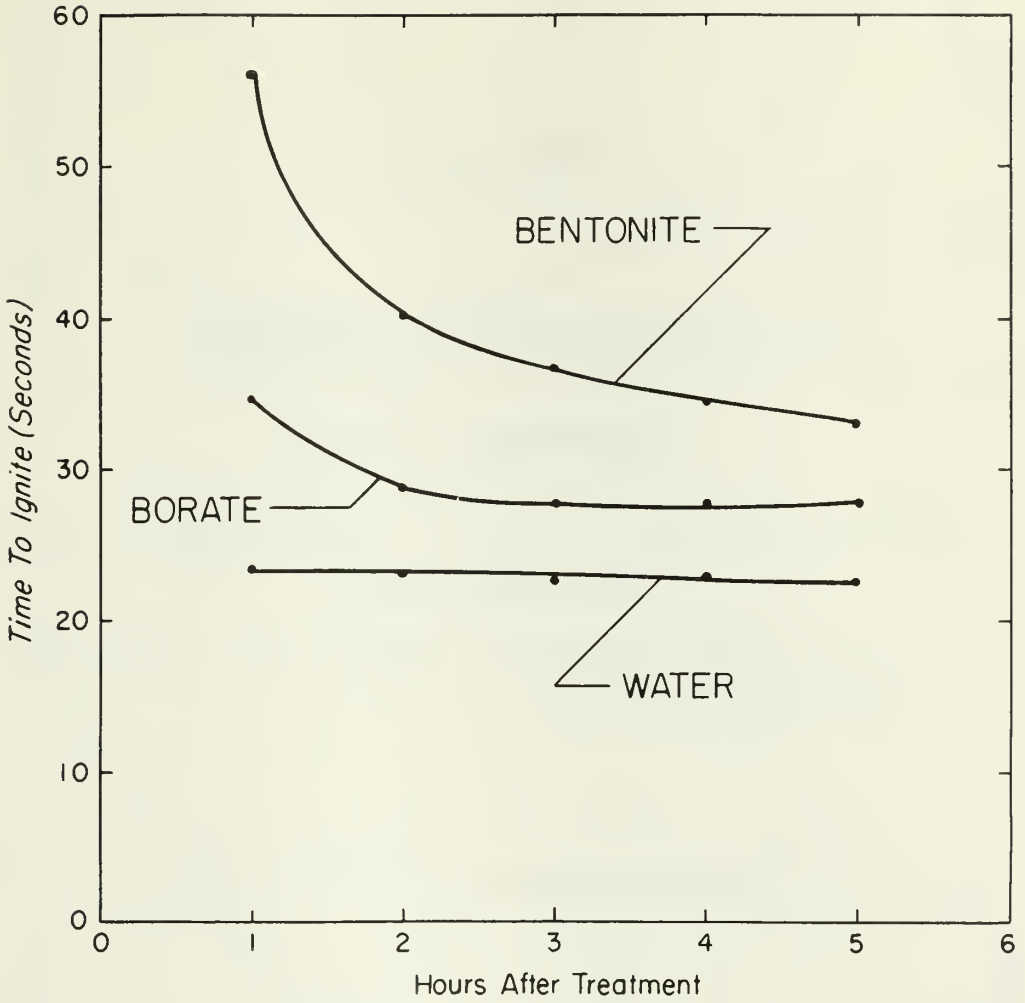

Figure 12.--Effect of drying on ignition time. (Muffle oven temperature: 1,000° F.)

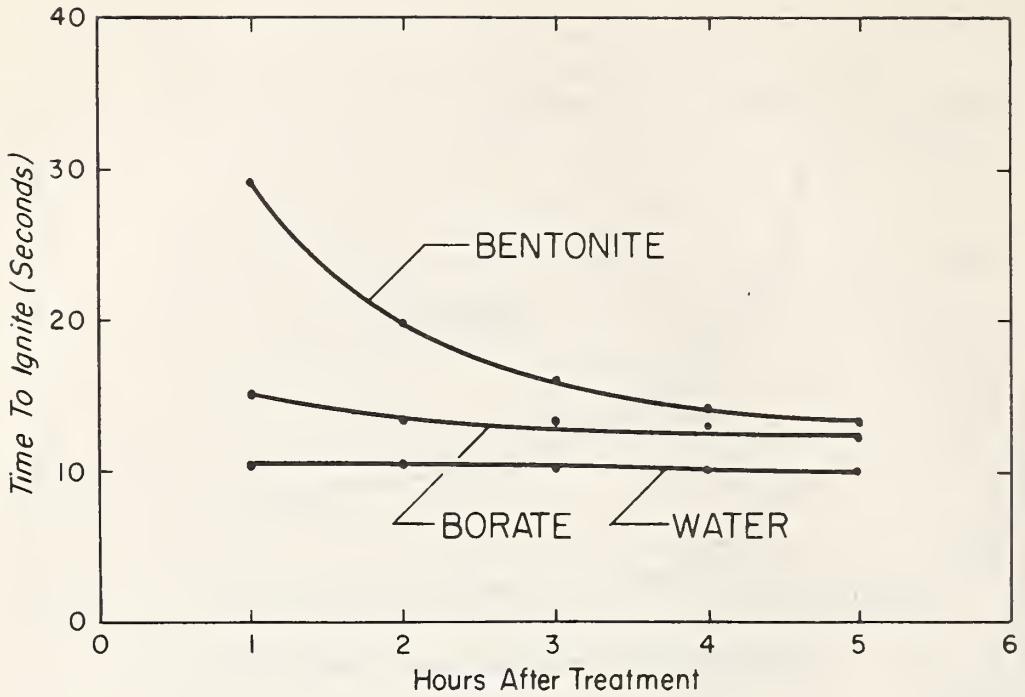

Figure 13.--Effect of drying on ignition time. (Muffle oven temperature: 1,200° F.)

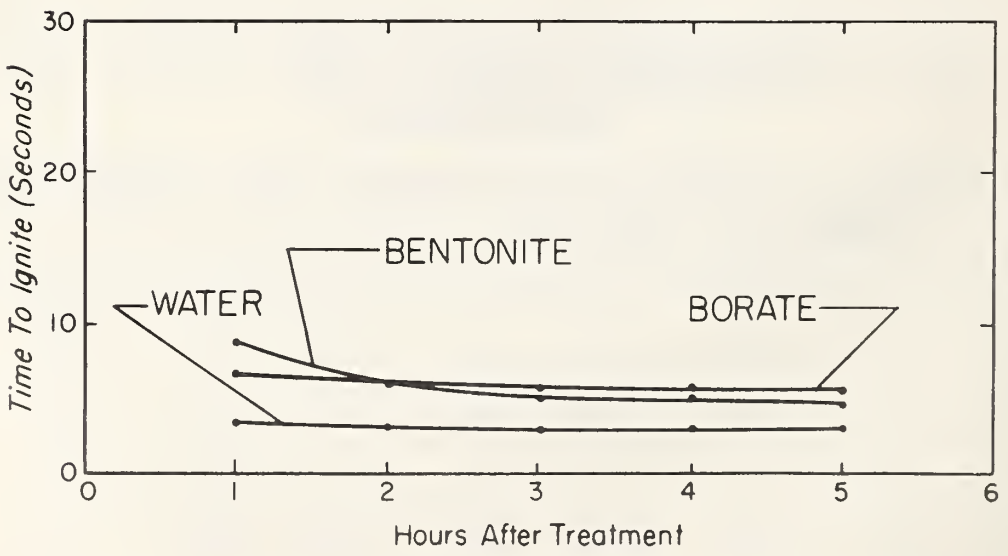

Figure 14.--Effect of drying on ignition time. (Muffle oven temperature: 1,500° F.)

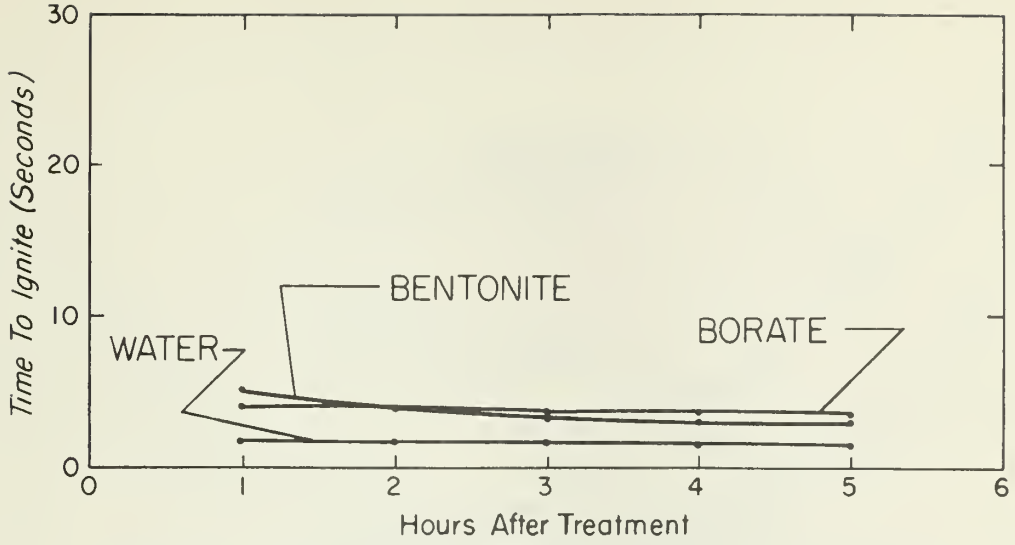

Figure 15.--Effect of drying on ignition time. (Muffle oven temperature: 1,700° F.)

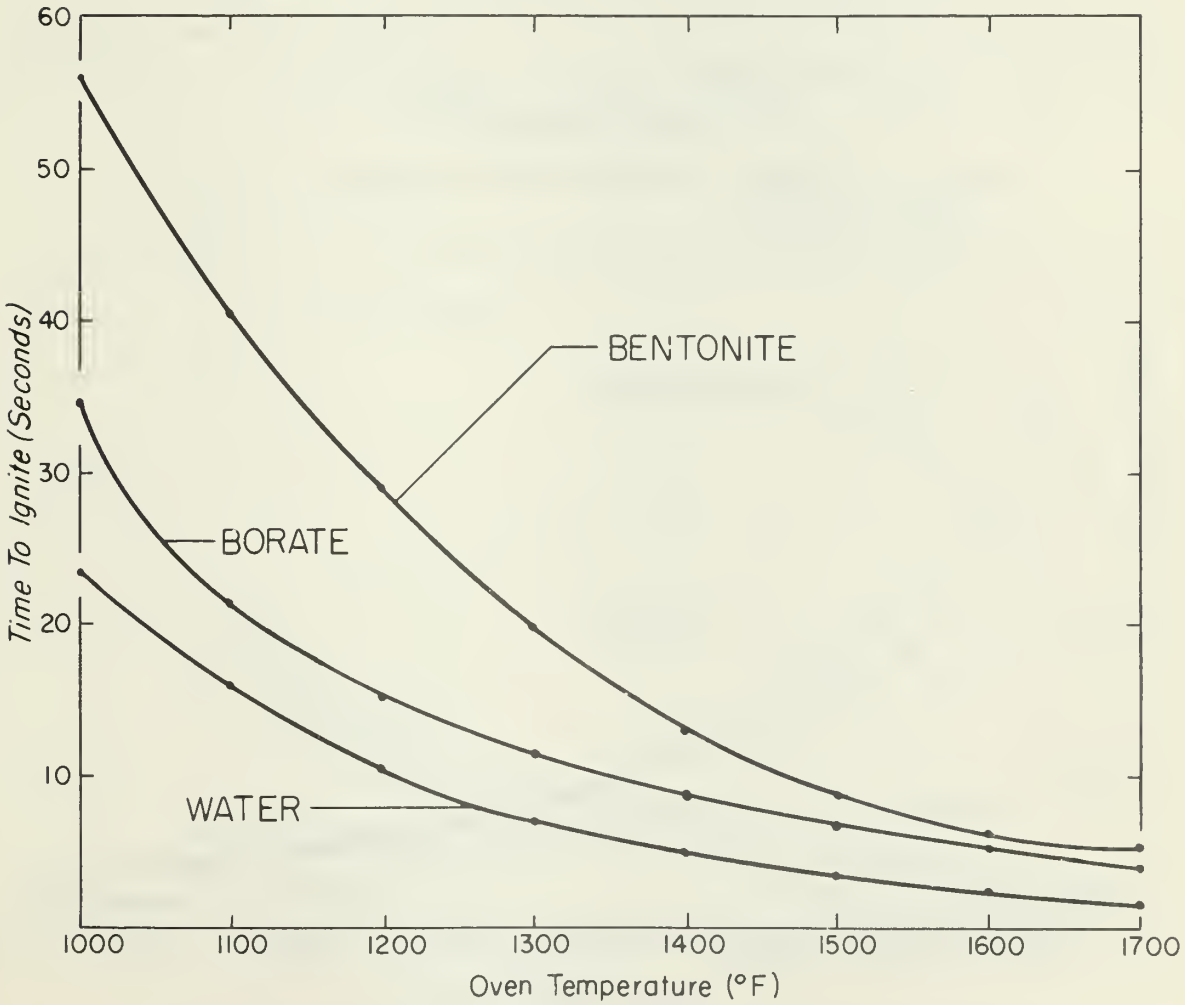

Figure 16.--Effect of temperature on ignition time 1 hour after treatment.

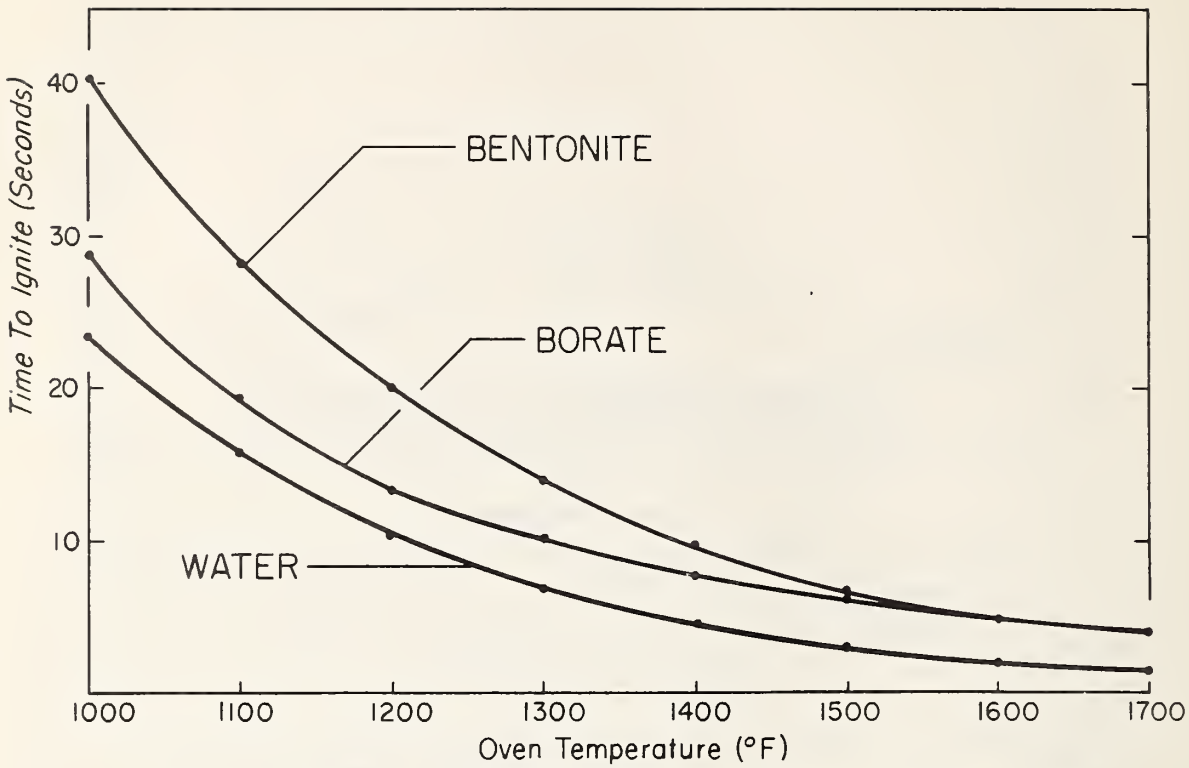

Figure 17.--Effect of temperature on ignition time 2 hours after treatment.

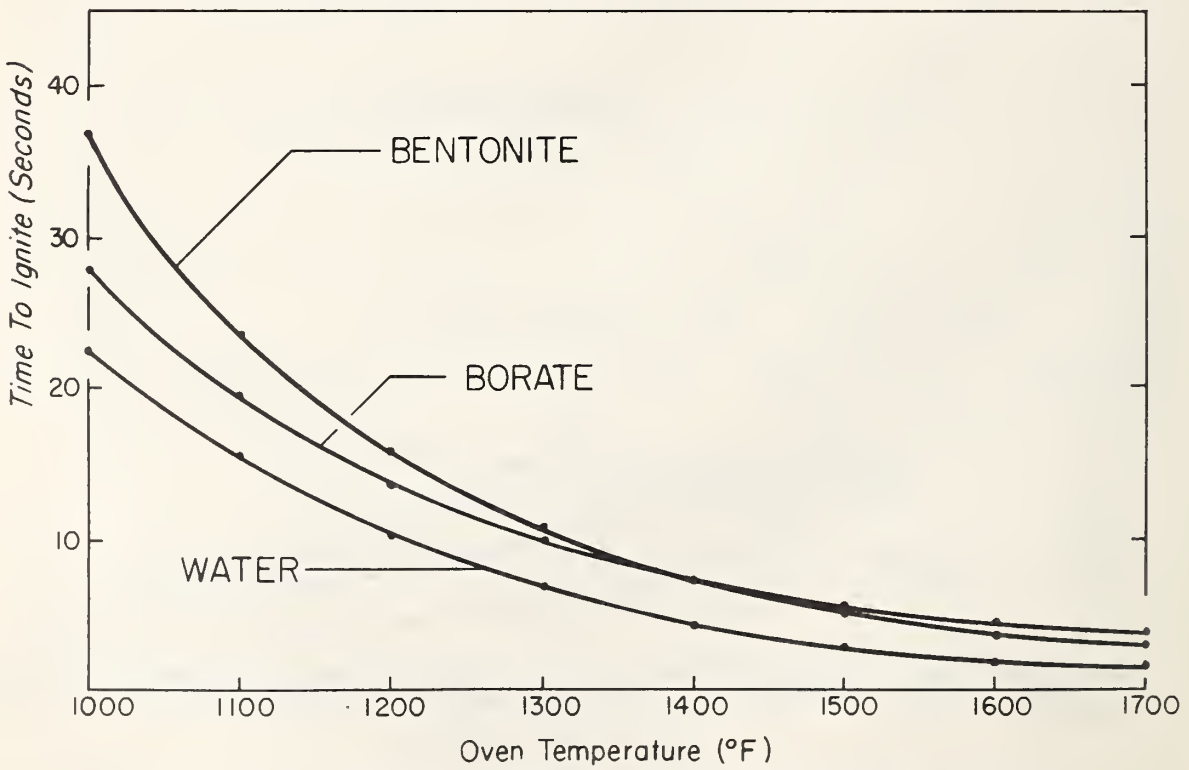

Figure 18.--Effect of temperature on ignition time 3 hours after treatment.

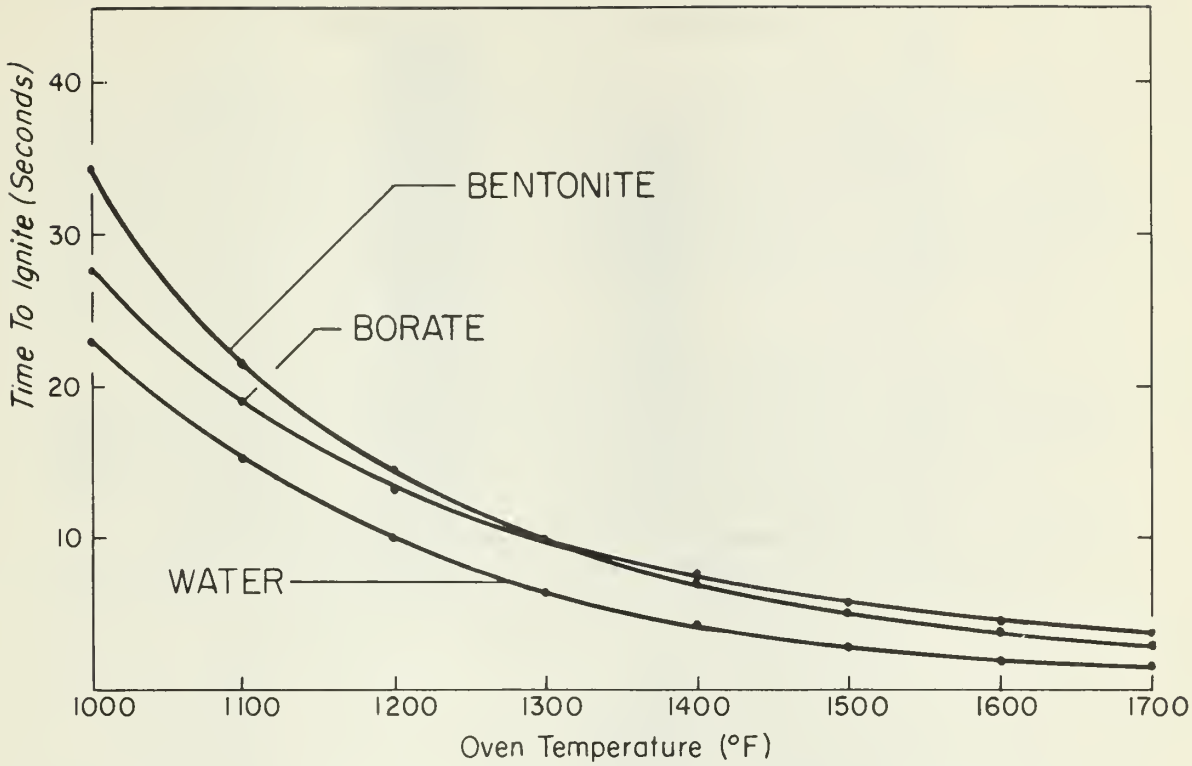

Figure 19.--Effect of temperature on ignition time 4 hours after treatment.

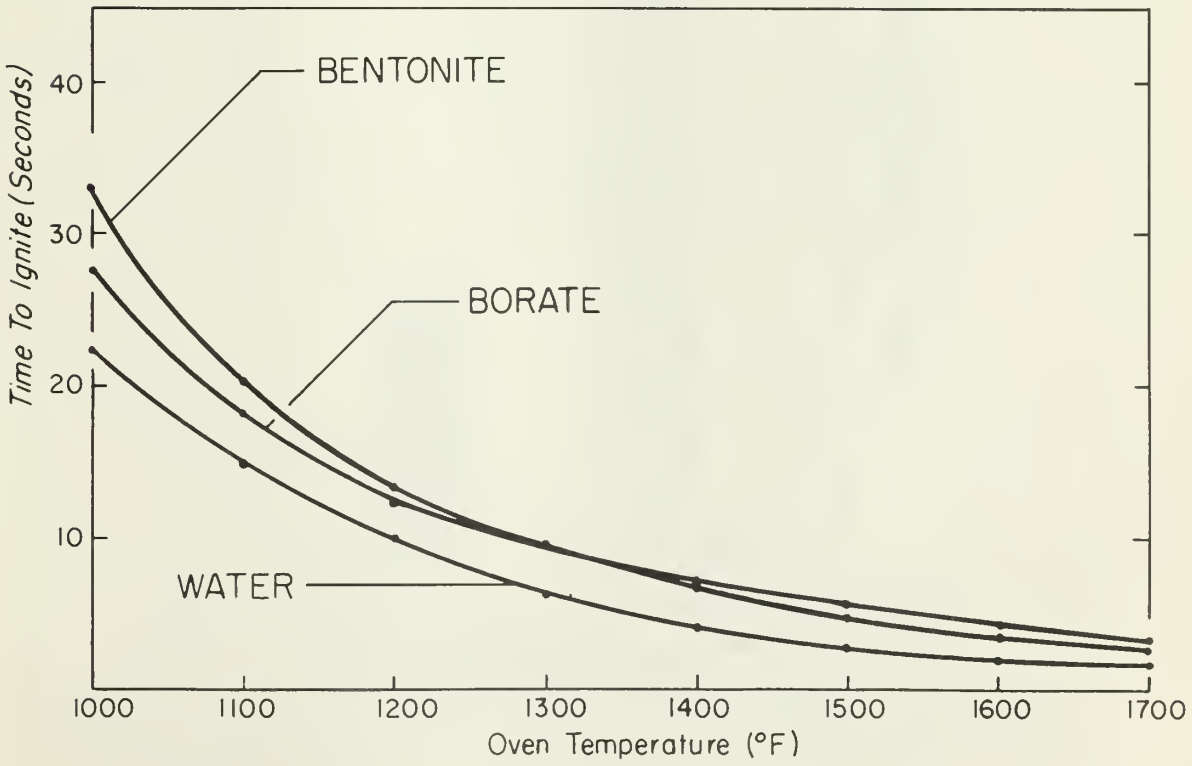

Figure 20.--Effect of temperature on ignition time 5 hours after treatment.

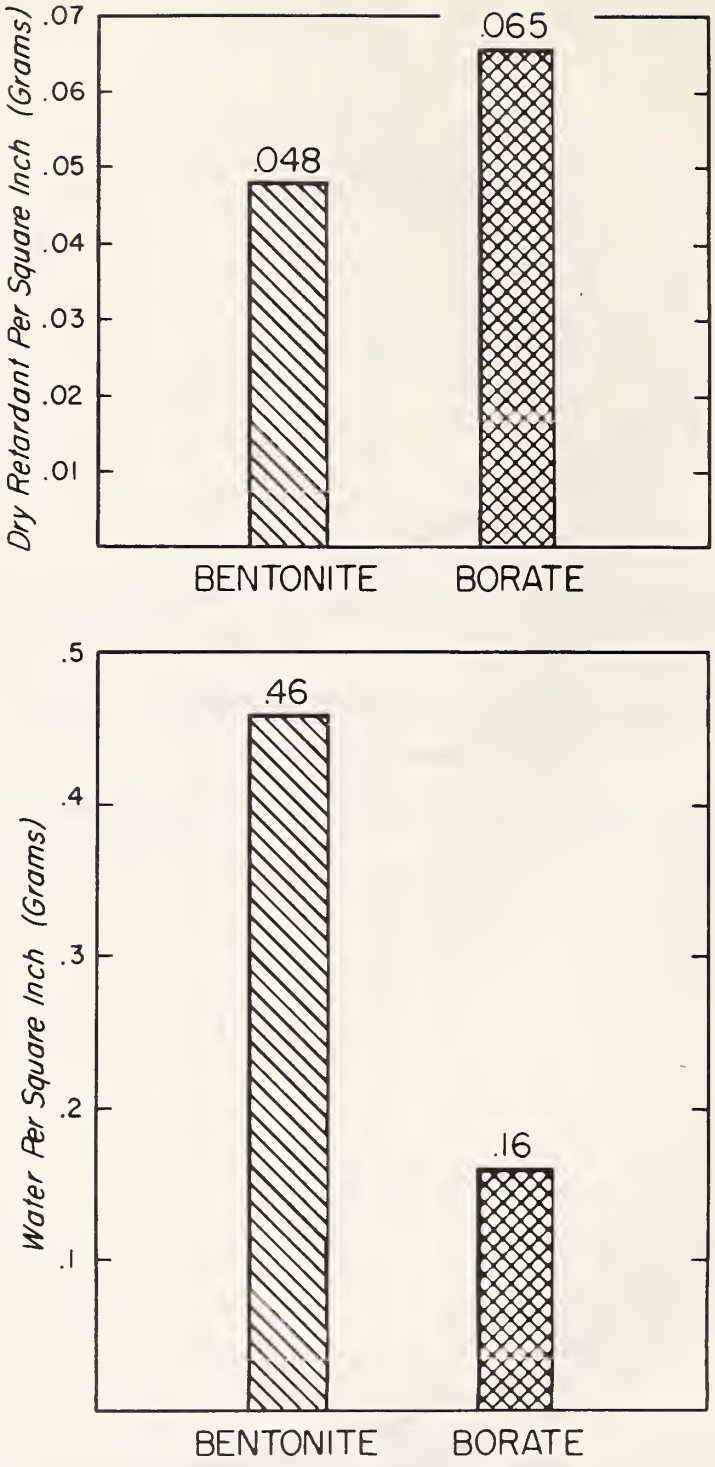

Figure 21.--Amount of retardant and water in coating of bentonite- and borate-treated fuels.

Evaporation of Water from Slurries

A comparison of the amount of dry retardant material and of water contained in the slurries of bentonite and borate used to treat fuels in the laboratory radiation and ignition tests is shown in figure 21. The bentonite slurry was mixed in the proportion of .94 pounds of dry bentonite per gallon of water and borate slurry in the proportion of 3.5 pounds of dry borate per gallon of water. The graphs show the relatively large amount of water absorbed by the lesser amount of dry bentonite.

Figure 22 shows the amount of water remaining in the coatings of fuels treated with these bentonite and borate slurries after each of the 5 hourly intervals during the tests (drying oven temperature of 120° F.). The relatively large amount of water held by bentonite up to 2 or 3 hours is readily seen.

Data for figures 21 and 22 are averages of figures obtained from weighing the treated fuels after each hour of drying as described in the procedures for the radiation and ignition tests.

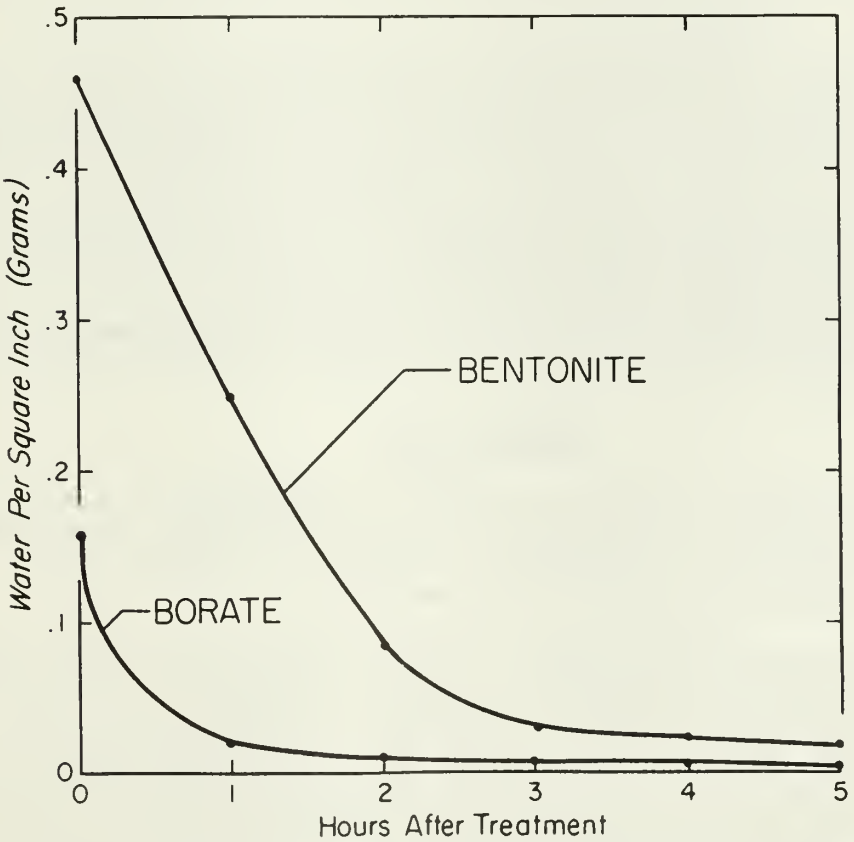

Figure 22.--Amount of water remaining in coatings of bentonite- and borate-treated fuels during 5-hour drying period in ignition and radiation tests.

ABRASION TESTS

Homart Pump

During the period November 3 to December 31, 1958, the Arcadia Equipment Development Center tested a Homart Model 776-2402 pump on Aqua-Gel, an oil well-grade swelling bentonite. This pump is the first to be tested by the Center with bentonite and is the type of pump used to transfer bentonite slurries throughout the field tests. A mixture of .75 pounds of bentonite per gallon of water, the proportions selected for general use after field experience, was used in the abrasion tests.

The Homart pump is a low pressure, self-priming centrifugal pump. It is manufactured by Marlow Pumps and sold by Sears, Roebuck and Company. It is mounted on a Briggs and Stratton 14 FB engine. The inlet and outlet of the pump are of 2-inch diameter. For the test the pump was fitted with a 2-1/2-inch suction hose, and 1-1/2-inch pressure hose. At the beginning of the test, at full throttle, the pump turned 2,928 rpm, and pumped 103.6 gpm at 30.5 psi. Running under continuous load conditions, the pump turned 2,562 rpm, and put out 92.2 gpm at 25.0 psi. At the end of 100 hours of operation, the pump was turning 2,568 rpm, and pumping 84.8 gpm at 25.0 psi.

After 100 hours of operation, the pump was disassembled for inspection. The mechanical seal was the only part which showed any indications of wear. It is estimated that the seal had used from 10 to 20 percent of its service life. The impeller and diffuser ring showed no wear; in fact, they were not even shiny from contact with the bentonite. The loss in volume during the course of the test was probably due to the evaporation of some of the water, which made the slurry heavier and more viscous. No dispersants were used in the bentonite slurry in these tests.

This test showed that the service life of the Homart is quite satisfactory while pumping bentonite.

Berkeley Pump

From April 4 to April 17, 1959 the California Division of Forestry tested a new Berkeley two-stage, centrifugal, Model 2EQ2, pump with Aqua-Gel. A mixture of .74 pounds of bentonite per gallon of water was used in the abrasion test.

The Berkeley pump uses a Hercules IXLB gasoline engine and is manufactured by the Hercules Company. The pump is rated with water at 250 gpm at 120 psi and 120 gpm at 250 psi. It is the type of pump used on about half the firetrucks of the Division of Forestry. The seal of the new pump tested was converted from its original chevron type packing with an adjustable gland. The conversion was made by boring out the packing receptacle and putting in two spring-loaded, leather type oil seals with a nut holding the seals in position. The inlet of the pump is 3 inches and the outlet, 2-1/2 inches.

For the test the pump was fitted with a 2-1/2 inch suction hose and a 1-1/2 inch discharge hose. Throughout the test the pump operated at 2,500 rpm and pumped 50 gpm at 125 psi.

The pump was checked for wear after 55 hours of operation and again after 108 hours of operation when the seals failed. Total wear of pump parts in inches was:

	After 55 hours	After 108 hours
First Stage		
Suction hub	.005	.007
Small hub	.003	.0055
Volute case (6 pts)	.003 - .017	.004 - .021
Second Stage		
Suction hub	.0125	.013
Small hub	.003	.005
Volute case (6 pts)	.010	.011 - .014
Tail shaft	.001	1/
Volute bushing	.007	.009

1/ Tail shaft grooved and needed hard surfacing after 108 hours.

In addition, the impeller in the first stage lost 7 grams of weight after 55 hours and an additional 3 grams after 108 hours, while the impeller in the second stage lost 15 grams after 55 hours and an additional 10 grams after 108 hours.

If the seals had lasted, the pump could have continued in operation after 108 hours. This test showed that the service life of the Berkeley pump is satisfactory while pumping bentonite slurry and indicated that Aqua-Gel bentonite is substantially less abrasive than sodium calcium borate when used with the Berkeley 2-stage pump (Miller and Wilson, 1957).

Table 4.--Summary of bentonite use by air tankers, 1958

Fire	Date	Location[1]	Name of fire	Final size of fire	Fuel type	Weather			No. drops	Total vol. Bent.	Fire action following bentonite drops		
						Temp	R.H.	Wind sp.			Stopped	Flanked	No effect
				Acres		°F.	%	mph		Gals.			
1	8/31	Mendocino	L. Wikersham	4	Brush	-	24	10	1	180	x		
2	8/31	Lake	Payne	Spot	Woodl-grass	100	19	5	1	180			x[2]
3	8/31	Napa	Moskowite	325	Brush	98	32	6	1	120		x	
4	9/1	Lake	M. Barney	80	Brush	94	22	9	4	600		x	
5	9/1	Lake	Roadside #18	7	Grass	95	22	18	1	180	x		
6	9/1	Lake	Jordan	1	Grass	-	-	-	1	180	x		
7	9/2	Napa	C. Gamble	10	Woodl-grass	84	25	6	2	300	x		
8	9/4	Mendocino	C&R Lbr. Co.	3	Slash	84	27	13	1	180		x	
9	9/25	Riverside	Green River	220	Brush	78	15	18	1	600	x		
10	9/26	San Diego	Houser #2	540	Brush	70	32	13	2	1,200		x	
11	10/3	Angeles NF	Monrovia	14,000	Brush	-	-	-	9	5,400		x	
12	10/4	San Bernardino	Pole	3,705	Brush	84	20	0	2	1,200		x	

1/ Name of county for California Division of Forestry fires; name of national forest (NF) for U. S. Forest Service fires.

2/ Fire already controlled by ground forces.

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